Monthly Progress Report 4

DEVELOPMENT OF A LOW-NOISE, COLD-CATHODE TRAVELING-WAVE TUBE

This report covers 1 January 1965 to 31 January 1965

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prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
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Contract NAS 5-9002

I. OBJECTIVE

The objective of this program is the development of a Schottky cold cathode suitable for installation as an electron beam source in an ultralow-noise traveling-wave tube, and the development of a 6 Gc traveling-wave tube adapted for using this cold cathode. The cathode development task is being performed by Stanford Research Institute and the responsibility of the entire program and of the traveling-wave tube development rests with Microwave Electronics Corporation.

Particular tasks include the identification and development of material technology, fabrication techniques, and emission tests (SRI), and the life testing, development of processing and bake-out techniques, and integration of the cold-cathode emitter into a TWT vacuum envelope with known low-noise characteristics when operated with a thermionic cathode.

The ultimate objective is the delivery to NASA of a cold-cathode 6-Gc traveling-wave tube with a 1-milliwatt saturated power output level derived from a beam current of 150 microamperes, and an objective noise figure of 3 db.

II. PROGRESS DURING THIS REPORT PERIOD

Task 1: Development of Cold Cathode

Progress on this task is described in the attached SRI Monthly Progress Report.

Task 2: Development of Cold Cathode Processing Techniques

This task has been completed and is awaiting successful achievement of cold-cathode emission.

Task 3: Traveling-Wave Tube Design

The TWT was designed and will be fabricated during the ensuing month. Analysis of the electron gun, utilizing a computer, was performed. Calculation of the beam profile and axial potential profile was accomplished. Noise figure calculations indicated high noise figures for this design, but based upon the beam profile configuration, low noise figures should be obtainable.

Task 4: Study of Noise Properties

Noise properties of electron beams have been studied. The area of concentration has been concerned with beam ripple and amplification of noise waves with a rippling beam.

III. PROGRAM FOR NEXT INTERVAL

Stanford Research Institute's program is presented in Appendix A.

Microwave Electronics Corporation will

- evaluate the TWT, after the design as required to achieve low noise figures and
- establish, in conjunction with SRI, techniques for fabricating the cold cathode.

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

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Monthly Progress Report 3
Covering the Period 1 January to 1 February 1965
Stanford Research Institute Project 5175

COLD CATHODES FOR LOW-NOISE TWT APPLICATIONS

by

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Contract SRI 010165

Prepared for

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Order NAS 5-9002.

Copy No. 11

I OBJECTIVE

The objective of this program is the development of a hot-electron cold cathode for a low-level traveling-wave tube.

II WORK SUMMARY

A. Theoretical

The qualitative valence theory of metal-semiconductor contacts was studied further. As a result, a quantitative theory has been evolved that utilizes the concept of electronegativity. A comparison has been made between theoretical and experimental barrier heights for a large number of metal-semiconductor combinations. When corrected values of work function for the various metals are used instead of the mean values as tabulated by Michaelson,* satisfactory agreement is obtained between the new theory and experiment. No such agreement, on the other hand, is obtainable from simple Schottky theory. The only other way to account for the results is through the use of the concept of surface states. The difficulty with surface-state theories is that no independent check can be made on surface-state densities. The electronegativity theory, on the other hand, can predict barrier heights from independent measurements of work functions, electron affinities, and electronegativities. This new theory has been written up as a paper to be submitted to Journal of Applied Physics, a copy of which will be included in the next quarterly report.

One difficulty in using the theory is that electron affinities have not been measured for all semiconductors. This difficulty applies to Schottky and surface state theories also. For example, the electron affinity of ZnO has evidently not been measured. Using the new electronegativity theory and the results of barrier height measurements, an electron affinity of 4.8 ev can be calculated for ZnO. This compares with a measured value of 4.8 ev for CdS, a first cousin of ZnO. This high value of electron affinity satisfactorily explains the impossibility of obtaining high barriers for metals deposited on ZnO.

The electron affinities of TiO_2 and α-SiC have also evidently not been measured. From the electronegativity theory one can infer a value of 4.5 ev for TiO_2 and 3.15 ev for α-SiC.

This new theory should prove to be very useful in future cathode work in the proper selection of suitable metal-semiconductor combinations.

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*H. B. Michaelson, J. Appl. Phys. 21, 6, pp. 536-540 (June 1950).

B. Experimental

A grid mask was fabricated for evaporating a thick Pt surface grid. Three substrates can be handled at once during the evaporation run. The mask has proved to be satisfactory in all respects. Grid lines about 1-1/2 mils wide spaced about 2-1/2 mils apart are obtained.

Two complete cathode structures have been assembled, using the modified substrate design shown in Fig. 2 of the Second Quarterly Report, with the addition of a locating collar for the Ti pellet.

Both cathodes have been tested on a Vac-Ion pumping station. In both cases short circuits developed. Hot-electron emission of about 0.3 μa was nevertheless evidently obtained on the first cathode and about 2 μa on the second cathode. From the fast response to sudden bias voltage changes it was deduced that the observed current was hot-electron emission and not thermionic emission. (Thermionic emission was obtainable from both cathodes if sufficient bias current was applied for more than a few seconds.)

The first cathode was taken apart and carefully inspected. From the appearance of the Ti pellet it was concluded that the short circuit was at the edge of the lip on the top hat.

Careful inspection of the second cathode during operation at very high bias currents indicated a bright hot-spot at the edge of the lip on the top hat. Thus it appears that the top hat is shorting to the substrate for some reason. Small burrs at the edge of the lip might be responsible. We plan to take special precautions in future top-hat fabrication to eliminate any possible burrs.

Three additional substrates have been ground to dimensions and additional pellets are being processed for assembling additional cathodes for test. These new pellets will incorporate an insulating ring around the periphery, with an evaporated metallic ring over the insulating ring. This metallic ring should facilitate the electrical contact between the top hat and the Pt grid lines with a minimum of contact pressure.

Single crystals of α-SiC have been given an initial evaluation for possible cathode use. The results indicate that the crystals are inhomogeneous and therefore not suitable.

III CONFORMANCE TO SCHEDULE

We are approximately on schedule, using the revised schedule set up in December. We hope to be able to start supplying cathodes on a small scale to Microwave Electronics Corporation toward the end of February.

IV ANALYSIS OF WORK PROGRESS

The electronegativity theory of metal-semiconductor barriers could be an important contribution to this field.

On the experimental side, two complete cathodes have been assembled and tested. The first cathode developed considerable leakage prior to a 300°C bake-out but survived the bake-out with no change. The second cathode developed leakage some time during a 350-to-400°C bake-out. Thus we cannot say for sure yet what a safe bake-out temperature will turn out to be, only that it is higher than 300°C. Hot electron emission was evidently obtained on both cathodes at dc bias voltages between about 1.5 and 2.0 volts. In future tests pulsed bias may be used in addition to dc bias to gain further information about the operation of the cathodes.

The results obtained from these first two cathodes seem to indicate that with certain modifications the design may be adequate. Mechanically and thermally the cathodes appear to be very rugged.

V RELIABILITY

The forward current through the TiO_2-Pt diode on life test has diminished with time. Other workers have noted such decreases and have attributed it to oxidation of the partially-reduced oxide. Such oxidation could not take place in a good vacuum, of course. We are thus hopeful that cathodes in vacuum will possess long-term stability. Actually the reverse process could occur in vacuum, particularly at elevated temperatures such as occur during bake-out. That is, the oxide could become even further reduced, leading to increased forward currents. Hopefully this will not occur at normal operating temperatures, however.

VI ADEQUACY OF FUNDS

A slightly higher level of funding appears to be required. About a 15-percent increase in rate of funding would approximately match the current spending rate.

VII PERSONNEL CHANGES

No changes in personnel were made during January 1965.

VIII PROGRAM FOR JANUARY 1965

(1) Assemble and test additional cathodes incorporating improvements designed to eliminate the short circuits obtained on the first two cathodes.

(2) Begin delivery of cathodes to MEC.

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